Modeling Sedimentary Deposits on the Continental Margin

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LONG TERM GOAL

The long-term goal of my research group is to construct mathematical descriptions of the processes that form sedimentary deposits at all spatial scales on continental margins, from storm beds to the deposits of 100,000 yr sea level cycles; and to conduct numerical experiments leading to the prediction of the sedimentary fabric (structure, stratification pattern) of the resulting deposits.

OBJECTIVES

A first objective is to investigate the fabric (pattern) of seabed stratification on continental margins at small time and space scales (1 cm-50 cm depth into the seabed; 1 hr-3 yrs sedimentary record). To this end, we are testing the hypothesis that on muddy shelves such as the northern California shelf, Holocene event stratigraphy consists of the deposits of high-concentration storm regimes associated with river floods, alternating with deposits of low-concentration storm regimes. In order to conduct the test, we have developed several "deterministic" algorithms, in collaboration with our subcontractors, Alan Niedoroda and Chris Reed, at URL Greiner Woodward Clyde, Tallahassee. These algorithms, (EVENT, RESUSPEND, and TRANSPORT), that are driven directly by STRATAFORM and NOAA current meter records.

At intermediate spatial scales (1 -20 m depth into the seabed; 1-1,000 yrs), we are testing a second hypothesis. The hypothesis states that facies assemblages are stacked on, or are capped by, erosional bounding surfaces (source diastems,) in patterns reflecting fluid power gradients in the parent dispersal system; and that these patterns are responses to progressive sorting and stratal condensation mechanisms. At these intermediate time and space scales, flood and storm current records are not available. In order to conduct the test, we have embedded EVENT in an algorithm (FACIES) that is driven by probability density functions describing flood and storm current frequencies.

At large time and space scales (1 -1,000 m depth into the seabed; 100-2.5 million yrs) we are testing a third hypothesis. The hypothesis states that that depositional sequences can be explained in terms of shifts in the equilibrium configuration of shelf surface in response to changes in sea level, the rate and character of sediment input, and the hydrodynamic climate. In order to conduct the test, we have developed, in cooperation with Mike Steckler of Lamont Doherty Earth Observatory, a combined stratigraphic model (morphodynamic-geodynamic model; SEQUENCE).

APPROACH

We propose to test the short-term sedimentation ("flood" bed) hypothesis by driving event bed simulation directly from time series of bottom velocity and concentration measurements, and by

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comparing these hindcasts with observations. At ODU, we have developed a simplified 2-D event bed model (EVENT). The hypothesis is being tested by simulation of the 1995-1997 stratigraphy of the Eel River sector of the northern California shelf, as revealed in time series obtained from STRATAFORM tripods. The simulations are constrained by the box cores collected on the 1997 MELVILLE Cruise, the 1998 WECOMA and CORAL SEA cruises and the 1999 THOMPSON cruise. These samples have been subject to grain size analysis and Xradiography. Initial studies are taking place at the 50, 60, and 70 m stations of the S, O and K lines and on 60M and 60Q. A statistical model (Markov Chain model) of grain size variation in the first 15 cm of the seabed is being constructed in order to provide constraints for EVENT simulations. Eventually, the full data M9707 data set will be subjected to correlation length-scale analysis for grain size and stratal thickness, for this purpose.

We propose to test the hypothesis for intermediate scale sedimentation (Facies assemblage hypothesis) by linking deterministic algorithms for boundary layer sedimentation (EVENT) with a probabilistic algorithm for stratal succession. (FACIES; Zhang et al., 1997, in press). I and students are incorporating in this model the effects of variable sea level change, sediment input and hydraulic climate. We will compare results by statistical means with observations of box cores, piston cores and seismic records. We will coordinate with NRL in the development of the Seabed classification system (high resolution profiling system) and with NRL in laboratory intercalibration of grain size methods.

In order to test the hypothesis for long term sedimentation (equilibrium margin hypothesis) We have combined the morphodynamical model for continental margin evolution developed by URS Greiner--Woodward Clyde (1995) with Mike Steckler's (1993) geodynamical model, leading to a combined stratigraphic model (SEQUENCE). Initial results are exciting, and we have several papers in press (Carey et al., in press, in revision). In addition, the Tallahassee group has developed a preliminary expansion of the algorithm in which multiple grain sizes are transported and deposited . We are modifying SEQUENCE to deal with multiple grain sizes (MULTISEQUENCE), and will embed the intermediate scale model (FACIES) within it. The hydrodynamic coefficient of the SEQUENCE algorithm is being calibrated against a two-dimensional model of shelf Circulation (SLICE), also developed by the Tallahassee group.

WORK COMPLETED

We (Alan Niedoroda and Chris Reed, URS Greiner Woodward Clyde) have developed a 1-d model of sediment resuspension by waves and Currents (RESUSPEND). We (Chris Reed, URS Greiner Woodward Clyde) have developed a 2-D version of RESUSPEND that evaluates cross-shelf sediment transport in response to waves, tides and wind-driven currents. We (Shejun Fan, ODU) have developed a modified I-D version of RESUSPEND, in order to explore the behavior of high concentration regimes (ULTRASUSPEND). We (Yong Zhang and Shejun Fan) have Developed a two-dimensional variant of RESUSPEND and have fitted it with a probabilistic description of the wave climate, so sediment facies may be simulated (FACIES). We (Alan Niedoroda and Chris Reed, URS Greiner Woodward Clyde) have merged the morphodynamic and geodynamic models to form SEQUENCE. We (Chris Reed) have developed SLICE, a two-dimensional circulation model for the continental margin in order to calibrate SEQUENCE.

RESULTS

Simulations using EVENT and RESUSPEND show that short lived, coast-hugging, surface flood plumes, forming over the inner shelf of northern California during winter storms, leave behind them

slowly consolidating, high-concentration, near-bottom suspensions (fluid mud). Transport occurs by offshore bottom flows or as near bottom suspensions (remobilized fluid muds), responding to their own excess density. In this manner, high-energy winter re-sedimentation events, occurring within days or weeks of the flood, rework mud-rich material. Later spring and summer resuspension episodes involved higher levels of critical bed-shear stress, and a reduced supply of fine sediment. The resulting storm beds (Fig. 1) are thin and sand rich, partly as a consequence of *in situ* winnowing, and partly as a consequence of advection of sand from the further inshore (Fan et al., in press).

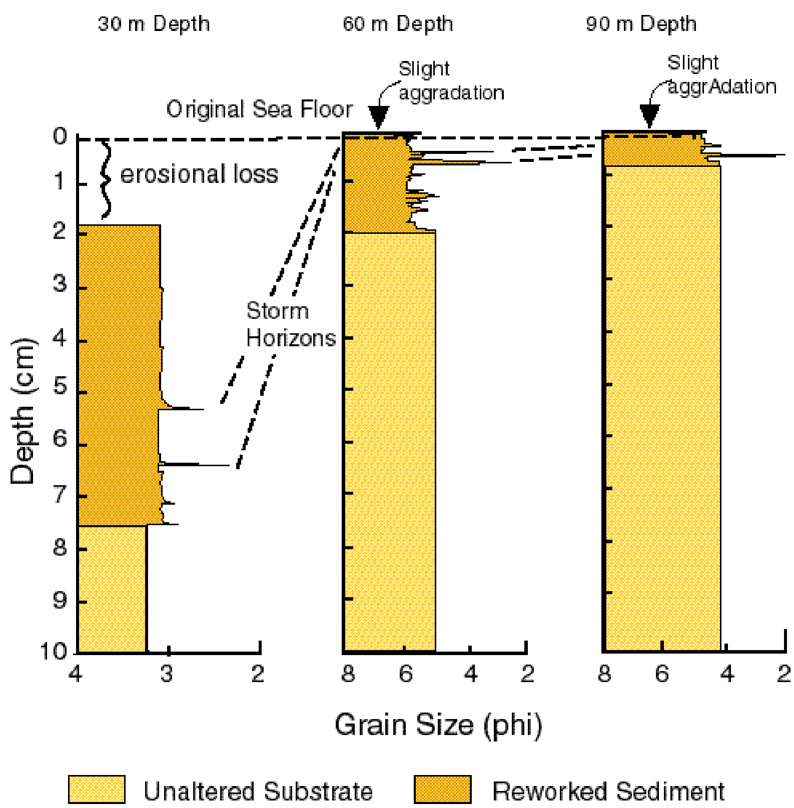

Fig. 1. Simulation by EVENT illustrating relationship between depositional regime and bed architecture on Northern California Shelf.

Simulations using FACIES (Fig. 2) show that on the northern California Continental shelf, storm beds have a zero preservation potential on the shore face. Further seaward, the beds from storms of lower frequency and greater wave power begin to be preserved, but beds from more frequent, weaker storms are not. Preservation potential increases with distance from shore and increasing water depth, so that on the outer shelf, all storm beds are preserved. The simulations predict the development the three basic facies of a high sediment-input shelf; an Amalgamated Sand Facies in the nearshore sector, an Interbedded Sand and Mud Facies on the inner shelf, and a Laminated or Bioturbated Mud Facies on the outer shelf.

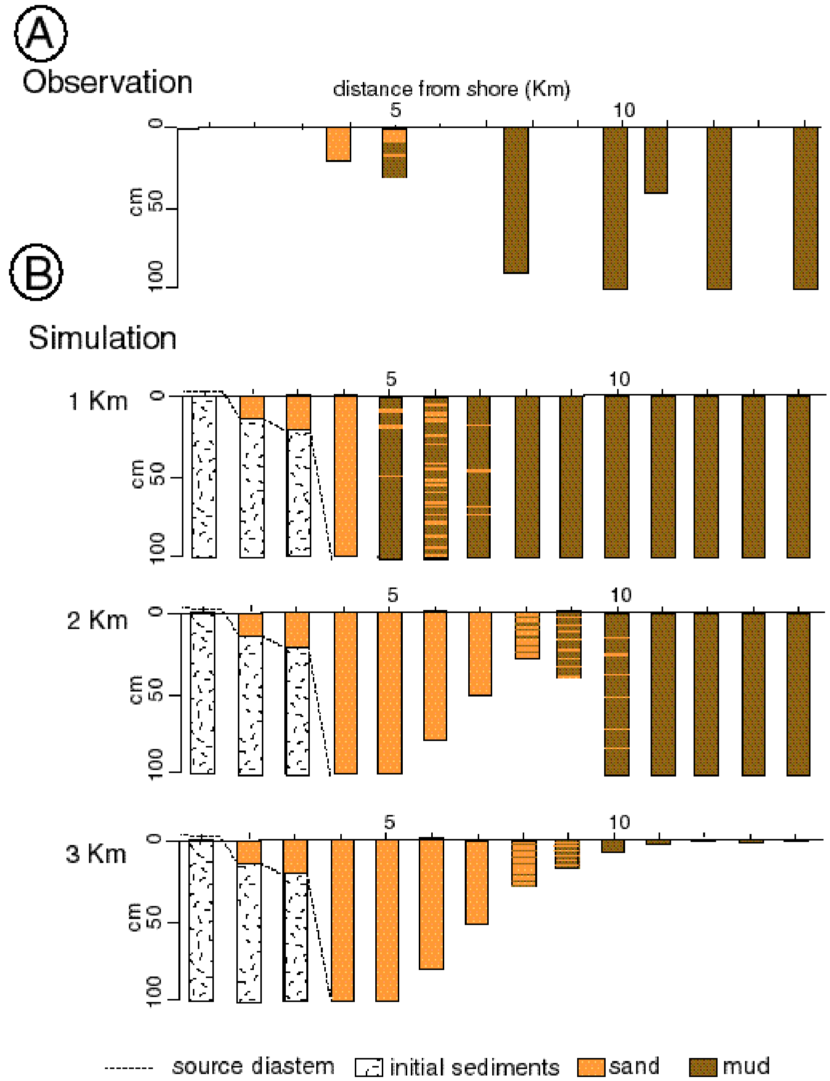

Fig. 2. Simulation by FACIES of the event stratigraphic section on the Northern California Shelf. A: Observations near the "S" sampling line of the STRATAFORM project, collected by Borgeld (1985). B: Simulations of Event stratigraphy displaced, 1, 2, and 3 km north from the Eel River mouth.

Simulations using SEQUENCE portray the Quaternary deposits of the Northern California montinental margin as a series of high frequency depositional sequences, in which the high stand systems tracts have been largely replaced by unconformable surfaces (Fig 3). As a consequence of ongoing tectonic activity, sedimentation is largely confined to the subsiding areas between rising anticlinal folds. The sequences are attempts by the Continental margin dispersal system to "restore" the equilibrium shelf configuration during a sea level oscillation.

IMPACT AND APPLICATIONS

EVENT will predict the geotechnical and acoustic properties of first meter of the sea floor. FACIES will predict the geotechnical and acoustic properties of first 10 meters of the sea floor. SEQUENCE

will predict seafloor structure at depths up to several kilometers, for foundation studies and petroleum exploration.

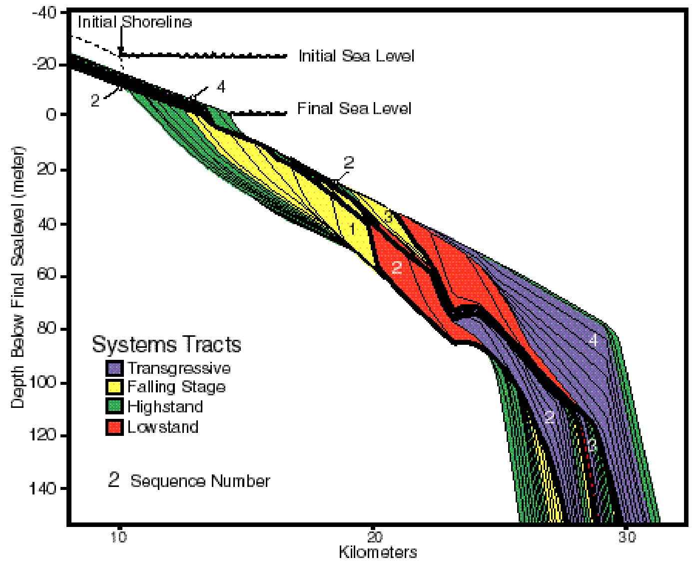

Fig. 3. Simulation of the deposits of a 125 K sea level oscillation on the Eel Sector on the northern California Shelf.

TRANSITIONS

We are, in structural terms, the most “downstream” component of STRATAFORM in the sense that we use the results of other STRATAFORM groups as constraining data. The process is linear however, but has feedbacks; our modeling results have lead to changes in the approach of our observationist colleagues (Mike Field’s seismic work, USGS, Menlo Park, and Neal Driscoll’s seismic work, WHOI). The larger oceanographic community outside of STRATAFORM are also consumers of our products. We are presently exchanging code with Peter Cowell, University of Sidney, Australia, and other members of the PACE group (Predicting Aggregate Coastal Evolution) funded by the European Economic Community.

RELATED PROJECTS

We are calibrating the models against dynamical data sets collected by STRATFORM investigators (Cacchione, Sternberg, and Wright). We are validating the models by comparison with the sea floor observations of other STRATAFORM investigators (Drake, Wheatcroft, Borgeld, Bentley,Traykovski, and Nittrouer). We are cooperating closely with ongoing STRATAFORM modeling efforts by Syvitski and students (INSTAR), and by Steckler at LDEO.

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